QUALITY AND ECONOMIES OF SCALE IN HIGHER EDUCATION: A SEMIPARAMETRIC SMOOTH COEFFICIENT ESTIMATION

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This paper proposes a semiparametric smooth coefficient cost model to study the university cost structure where coefficients are an unknown function of the university's overall quality. A local least square method with a kernel weight function is used to estimate the cost function, and a simple statistic for testing a parametric model of the additive quality versus the semiparametric smooth coefficient model is applied. Empirical results from 56 universities in Taiwan show that, taking quality into account, higher education is subject to diseconomies of scale. In all categories—comprehensive and science/technology and public and private universities—the current university scale in Taiwan is too big to be cost efficient. (*JEL* I21, H52, 9120)

I. INTRODUCTION

Institutions of higher education comprise knowledge creation (research) and knowledge dissemination (teaching). Thus, the university's mission is to deliver quality undergraduate and graduate education and to expand the frontier of academic research. Numerous studies (Verry and Layard 1975; Cohn, Rhine, and Santos 1989; deGroot, McMahon, and Volkin 1991; Nelson and Hevert 1992; Lloyd, Morgan, and Williams 1993; Dundar and Lewis 1995; Koshal and Koshal 1995, 1999) have investigated, as in the case of firms, the multiple-product cost function of producing the vector of outputs on undergraduate and graduate education and research. The cost structure of higher education is studied via the scale economies and the scope economies of the cost function. However, these measures of scale and scope economies may be elusive if the quality dimension of colleges and universities is not considered. Without taking into account the quality variation, in the short-run, a university can reduce the average cost of operation by lowering the quality. Universities with more congested educational facilities are substituting facility utilization for capital; universities with a higher student/faculty ratio and less research engagement are substituting quality of education for quantity of undergraduate and graduate enrollment. The consequence is an upward bias in estimating the economies of scale and scope. This conclusion is consistent with the early studies of Nelson and Hevert (1992) which showed that failure to control for class size in cost function may result in specification bias, and an economy of scale is evident if class size is allowed to expand.

Quality of higher education is multidimensional. Quality in instruction, faculty research, and the quality of educational environment are all significant factors determining the long-run university cost structure and the crucial determinants of the scale and scope economies of higher education. How and to what extent quality affects a university's operating cost depends on the goal and orientation of the institutions. Higher quality increases the university's cost

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ABBREVIATIONS

AIC: Average Incremented Cost
NSC: National Science Council

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of operation. But, in a large research-oriented university, a disproportional share of the budget often benefits the graduate, not the undergraduate program. It is unrealistic to assume that quality affects only the average cost and that the marginal costs of various educational programs are independent of quality. Quality is unlikely to be simply a neutral cost-shifting factor.

The purpose of this paper is to propose a university cost function and a semiparametric-estimating technique that treats quality as a nonneutral cost-shifting factor, which directly affects the marginal cost of outputs in undergraduate and graduate education. More precisely, the marginal costs of outputs are specified as a nonparametric smooth function of quality. A semiparametric specification of university cost is applied to 56 comprehensive and science/technology universities in Taiwan over the period 2000–2003.

II. SEMIPARAMETRIC COST FUNCTION AND ESTIMATION TECHNIQUE

Following the conventional multiproduct cost specification for higher education (Cohn, Rhine, and Santos 1989; deGroot, McMahon, and Volkin 1991; Lloyd, Morgan, and Williams 1993; Dundar and Lewis 1995; Koshal and Koshal 1995, 1999), the total cost (C) is specified as a quadratic function of outputs, undergraduate and graduate enrollments. However, the quadratic cost function is modified by allowing for the coefficients to be functions of quality in the following form:

$$(1)\quad C = \beta_0(Q) + \sum_{i=1}^{k} \beta_i(Q) Y_i + (1/2) \times \sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij}(Q) Y_i Y_j + \sum_{i=1}^{m} \alpha_i Z_i + \varepsilon$$

where C is the total cost of producing k educational outputs (Y), and Z_i is the ith institutional characteristics. The quality Q is an index relating to teaching (e.g., faculty/student ratio, class size), to research (e.g., publication, grant awards), and to the learning environment (e.g., learning facility and living space). Following Li et al. (2002), the coefficients, $\beta_i(Q)$ and $\beta_{ij}(Q)$, of outputs are assumed to be unknown functions of the quality. When $\beta_i(Q) = \beta_i$ and $\beta_{ij}(Q) = \beta_{ij}$, the specification reduces to the conventional augmented cost function with quality as the cost-augmenting, neutral cost-shifting factor via the varying intercept $\beta_0(Q)$. Koshal and Koshal (1995, 1999) specify a neutral cost-shifting specification with $\beta_0(Q)$ being linear in the average Scholastic Aptitude Test of entering freshmen, whereas Dundar and Lewis (1995) use reputation ratings of programs as an additive to the total cost.

The advantage of specifying the total cost as a semiparametric smooth coefficient model allows the investigation of the profile of the cost-quality relation observed in the data without setting a prior parametric functional form of the relationship.[1] For example, the marginal cost of the ith output:

$$(2)\qquad \mathrm{MC}_i = \beta_i(Q) + \sum_{j=1}^{k} \beta_{ij}(Q) Y_j$$

varies with the quality. Quality improvement in faculty/student ratio, in research facilities, or in dormitory living may incur a differential marginal cost in undergraduate and graduate education. And the marginal cost (the shadow price) of quality varies directly with the quality:

$$(3)\quad \mathrm{MC}_Q = \beta'_0(Q) + \sum_{i=1}^{k} \beta'_i(Q) Y_i + (1/2) \times \sum_{i=1}^{k}\sum_{j=1}^{k} \beta'_{ij}(Q) Y_i Y_j$$

where $\beta'(Q)$ is derivative of the smooth coefficient functions. An increasing or even a decreasing marginal cost of quality is a distinct possibility. Furthermore, when the semiparametric cost function is estimated, the ray economies of scale (Baumol, Panzar, and Willig 1982; Cohn and Geske 1990; Hashimoto and Cohn 1997) are estimated as:

$$(4)\qquad \mathrm{RES} = C \Big/ \sum_{i=1}^{k} (Y_i \times \mathrm{MC}_i)$$

The ray economies (diseconomies) of scale exist when RES is greater (less) than one. It is obvious that the ray economies of scale depend on quality, among other factors. The cost of expansion in two equal-size universities differs if the quality of the universities differs. The average

1. As pointed out by a referee that the issue of functional form extends to the specification of outputs (Y), and institutional characteristics (Z), not just the quality variable (Q). However, it is the focus of the impact of quality on university cost function that leads to the parsimonious specification in Equation (1).

cost of undergraduate expansion, measured by the average incremented cost (AIC), may differ from graduate expansion. The AIC of the ith (Y_i) output is defined as:

$$\text{(5)} \qquad \mathrm{AIC}_i = (C - C_{-i})/Y_i$$

where C_{-i} is the total cost of producing all other outputs other than the ith output, that is, $Y_i = 0$. The identification of the sources of ray economies of scale is measured by the product-specific economies of scale defined as:

$$\text{(6)} \qquad \mathrm{PSE}_i = \mathrm{AIC}_i/\mathrm{MC}_i$$

If PSE_i is greater (less) than one, economies (diseconomies) of scale are said to exist for the ith (Y_i) output. Again, the PSE depends on quality. Because the cost structure, marginal cost, and scale economies are all functions of quality Q, the semiparametric cost function specification allows the study of the trade-off between the quantity and quality issues of higher education.

The estimation of the semiparametric smooth coefficient cost function follows the local least squares method of Li et al. (2002). The Appendix at the end of the paper provides the rationale from preliminary empirical evidence and the basic idea of the local least squaretechnique.

Rewrite the cost function (Equation (1)) more compactly in matrix form for the tth university observation:

$$\text{(7)} \quad \begin{aligned} C_t &= \beta_0(Q_t) + Y_t^T\beta(Q_t) + Z_t^T\alpha + \varepsilon_t \\ &= (1, Y_t^T, Z_t^T)\begin{pmatrix}\beta_0(Q_t)\\ \beta(Q_t)\\ \alpha\end{pmatrix} + \varepsilon_t \\ &\equiv X_t^T\mathrm{B}(Q_t) + \varepsilon_t, \qquad t = 1, 2, \ldots, n \end{aligned}$$

where $X_t \equiv (Y_{it}, (1/2)Y_{it}Y_{jt}, Z_{it})^T$ is the observation vector with elements of Y_{it} ($i = 1, 2, \ldots, k$) and the elements of cross-products $Y_{it}Y_{jt}$ ($i, j = 1, 2, \ldots, k$). The superscript "T" stands for the transpose of a matrix. The vectors $\beta(Q_t) \equiv (\beta_i(Q_t), \beta_{ij}(Q_t))^T$ are the coefficients vector of Y_t. The observation vector $Z_t \equiv (Z_{1t}, \ldots, Z_{mt})^T$ is the vector of variables associated with the constant coefficient α. We briefly sketch the estimation procedure here and leave the details to the references in Li et al. (2002) and in Chou, Liu, and Huang et al. (2004).

An iterative procedure is applied to the partial linear model (Equation (7)). In the initial step, the coefficient α is treated as if it were a function of Q:

$$\text{(8)} \quad C_t = \beta_0(Q_t) + Y_t^T\beta(Q_t) + Z_t^T\alpha(Q_t) + \varepsilon_t$$

The regression is then estimated by applying the local least squares method of Robinson (1989), that is:

$$\text{(9)} \quad \begin{aligned} \overline{B}(Q) &\equiv \begin{pmatrix}\overline{\beta}_0(Q)\\ \overline{\beta}(Q)\\ \overline{\alpha}(Q)\end{pmatrix} \\ &= \left[(nh)^{-1}\sum_{t=1}^{n} X_tX_t^T K\big((Q_t - Q)/h\big)\right]^{-1} \\ &\quad \times \left[(nh)^{-1}\sum_{t=1}^{n} X_tC_tK\big((Q_t - Q)/h\big)\right] \end{aligned}$$

where $K(.)$ is the kernel function with bandwidth h. With the initial estimates $\overline{B}(Q)$, the constant coefficient vector α is re-estimated from a new regression by subtracting $\overline{\beta}_0(Q_t) + Y_t^T\overline{\beta}(Q_t)$ from Equation (7):

$$\text{(10)} \quad C_t - \overline{\beta}_0(Q_t) - Y_t^T\overline{\beta}(Q_t) = Z_t^T\alpha + u_t$$

where $u_t = (\beta_0(Q_t) - \overline{\beta}_0(Q_t)) + Y_t^T(\beta(Q_t) - \overline{\beta}(Q_t)) + \varepsilon_t$. Thus, in the second step, a $\sqrt{n}$-consistent estimator of α is obtained by the least squares regression of Equation (10):

$$\text{(11)} \quad \begin{aligned} \hat{\alpha} &= \left(\sum_{t=1}^{n} Z_tZ_t^T\right)^{-1} \\ &\quad \times \sum_{t=1}^{n} Z_t^T(C_t - \overline{\beta}_0(Q_t) - Y_t^T\overline{\beta}(Q_t)) \end{aligned}$$

The final step is to re-estimate $\beta_0(Q_t)$ and $\beta(Q_t)$ in Equation (7) by replacing α with the $\sqrt{n}$-consistent estimator $\hat{\alpha}$, that is:

$$\text{(12)} \quad C_t - Z_t^T\hat{\alpha}(Q_t) = \beta_0(Q_t) + Y_t^T\beta(Q_t) + v_t$$

where $v_t = Z_t^T(\alpha - \hat{\alpha}(Q_t)) + \varepsilon_t$. The final local least squares estimates of the smooth coefficients $\beta_0(Q)$ and $\beta(Q)$ are:

(13)

$$\begin{pmatrix}\hat{\beta}_0(Q)\\ \hat{\beta}(Q)\end{pmatrix} = \left[(nh)^{-1}\sum_{t=1}^{n}\begin{pmatrix}1\\ Y_t\end{pmatrix}\begin{pmatrix}1\\ Y_t\end{pmatrix}^T K\big((Q_t - Q)/h\big)\right]^{-1} \times \left[(nh)^{-1}\sum_{t=1}^{n}\begin{pmatrix}1\\ Y_t\end{pmatrix}\big(C_t - Z_t^T\hat{\alpha}(Q_t)\big) K\big((Q_t - Q)/h\big)\right]$$

The semiparametric smooth coefficient cost function (Equation (1) or (7)) underlines the significance of the nonneutral, cost-shifting factor of quality. The profile of the cost-quality relation is data-driven without a prior functional restriction as in the case of parametric specification. Li et al. (2002) propose a test on parametric models versus semiparametric smooth coefficient models. The null hypotheses that a certain parametric model is a correct specification can be stated as:

$$\mathrm{H}_0 : \begin{pmatrix}\beta_0(Q)\\ \beta(Q)\end{pmatrix} = \begin{pmatrix}\beta_0^*(Q)\\ \beta^*(Q)\end{pmatrix} \text{ almost everywhere.}$$

For example, the parametric model may specify that the cost-quality relation is neutral and is of a quadratic in Q. In this case, $\beta_0^*(Q) = \sum_{i=0}^{2}\delta_i Q^i$ and $\beta^*(Q) = \beta$. The alternative hypothesis is that the semiparametric model is the correct specification:

$$\mathrm{H}_1 : \begin{pmatrix}\beta_0(Q)\\ \beta(Q)\end{pmatrix} \neq \begin{pmatrix}\beta_0^*(Q)\\ \beta^*(Q)\end{pmatrix}$$

Under H_0, the following test statistic J_n has the asymptotic standard normal distribution:

$$J_n = nh^{1/2}\hat{I}_n/\hat{\sigma}_0 \tag{14}$$

where

(15)

$$\hat{I}_n = (n^2h)^{-1}\sum_{t}\sum_{s\neq t}(1 + Y_t^T Y_s)(\hat{\varepsilon}_t\hat{\varepsilon}_s) K\big((Q_t - Q_s)/h\big)$$

(16)

$$\hat{\sigma}_0^2 = 2(nh)^{-1}\sum_{t}\sum_{s\neq t}(1 + Y_t^T Y_s)^2(\hat{\varepsilon}_t\hat{\varepsilon}_s)^2 K^2\big((Q_t - Q_s)/h\big)$$

and the residual, $\hat{\varepsilon}_t = C_t - \tilde{\beta}_0(Q_t) - Y_t^T\tilde{\beta}(Q_t) - Z_t^T\hat{\alpha}$. The residual is obtained from the mixed regression, where $\hat{\alpha}$ is the semiparametric estimator of α from Equation (7), whereas $\tilde{\beta}_0(Q_t)$ and $\tilde{\beta}(Q_t)$ are the least squares estimators of the benchmark parametric linear regression. Under the alternative hypothesis H_1, the test statistic J_n approaches infinity as $n \to \infty$. Therefore, it is a one-sided test.

III. THE EMPIRICAL MODEL AND DATA

The semiparametric model outlined in the last section is applied to unbalanced panel data for the years 2000–2003 from 56 comprehensive and science/technology universities in Taiwan. The total number of panel observations is 200. As a result of the small sample size, a more parsimonious specification of the cost function is modeled in the empirical study. The quadratic cost function is modified to be:

(17)

$$\begin{aligned} C_{it} &= \beta_0(Q_{it}) + \beta_U(Q_{it})U_{it} + \beta_G(Q_{it})G_{it} \\ &\quad + \beta_{PhD}(Q_{it})\mathrm{PhD}_{it} + (1/2)\beta_{UU}U_{it}^2 \\ &\quad + \beta_{UG}U_{it}G_{it} + (1/2)\beta_{GG}G_{it}^2 \\ &\quad + \alpha_{\mathrm{public}}\mathrm{Public}_{it} + \alpha_{P2}P2_{it} \\ &\quad + \alpha_{P3}P3_{it} + \alpha_{P4}P4_{it} + \varepsilon_{it} \end{aligned}$$

where C_{it} is the total operating cost at the ith university in year t, which consists of labor and capital expenses. The labor expense includes the wages and benefits of both teaching and research faculty and the support staff. It is the dominant component of the total operating cost. The capital expense consists of building and equipment depreciation, expenses on library books, and other related capital expenses. The full-time undergraduate (U) and graduate (G) enrollments are two output measures.[2] The Ph.D., a dummy variable, takes a value of one for a university that offers a Ph.D. program; it takes zero, otherwise. The dummy variable Public takes a value of one for a public university and is zero for

2. Enrollment may be a poor measure of output if the attrition rate is not considered. Student attrition as a result of resign, drop out, or transfer can mean high costs for universities and low output measured in graduation rate. However, because of extremely low attrition rate in Taiwan, any measurable impact on cost would be insignificant. The attrition rates were 1.08% and 0.95% in 2002 and 2003 academic years, respectively.

a private institution. The statistical technique of principal components is applied to generate the quality measures from the four quality-related variables, the granted research projects per faculty (R) from the National Science Council (NSC), the faculty/student ratio (FS), the ratio of full professors to total faculty (PR), and the university building space per student (SP) in classrooms, laboratories, dormitories, and other educational facilities.[3,4] The quality index (Q_{it}) is the first principal component computed from the correlation matrix of (R, FS, PR, SP), that is:

$$Q_{it} = \lambda_R\Big(\big(R_{it} - \overline{R}\big)/S_R\Big) + \lambda_{\mathrm{FS}}\Big(\big(\mathrm{FS}_{it} - \overline{\mathrm{FS}}\big)/S_{FS}\Big) + \lambda_{\mathrm{PR}}\Big(\big(\mathrm{PR}_{it} - \overline{\mathrm{PR}}\big)/S_{\mathrm{PR}}\Big) + \lambda_{\mathrm{SP}}\Big(\big(\mathrm{SP}_{it} - \overline{\mathrm{SP}}\big)/S_{\mathrm{SP}}\Big) \tag{18}$$

where λs are the eigenvectors of the correlation matrix, and ($\overline{R}$, $\overline{\mathrm{FS}}$, $\overline{\mathrm{PR}}$, $\overline{\mathrm{SP}}$) and (S_R, S_{FS}, S_{PR}, S_{SP}) are the sample means and sample standard deviations of the respective variables. The second, third, and fourth principal components of the four related variables are denoted as $P2$, $P3$, and $P4$. Table 1 shows the proportion of total variation of (R, FS, PR, SP) accounted for by each component and the weights λs associated with the components.

TABLE 1
Principal Components of Quality-Related Variables

Variable	Variance Proportion	λ Weights			
		R	**FS**	**PR**	**SP**
Q	0.7669	0.5059	0.5003	0.4874	0.5061
$P2$	0.1214	0.3957	−0.4947	0.6019	−0.4862
$P3$	0.0723	0.5922	−0.5064	−0.4946	0.3850
$P4$	0.0394	0.4866	0.4985	−0.3944	−0.5994

By construction, the first principal component Q is then considered as the "overall" quality of the institution, which accounts for 76.69% of the total variation of quality-related variables. The first principal component has positive weights on each of the variables, (λ_R, λ_{FS}, λ_{PR}, λ_{SP}) = (0.5059, 0.5003, 0.4874, 0.5061), which indicates that the overall quality Q is, as expected, positively related to faculty research, faculty/student ratio, faculty composition, and the university building space.

The second principal component $P2$ accounts for 12.14% of the total variation. Although the first principal component captures the quality aspect of a university, the second principal component $P2$ is interpreted as an index of university characteristics other than quality. It has positive weights associated with faculty research ($\lambda_R = 0.3957$) and full-professor ratio ($\lambda_{\mathrm{PR}} = 0.6019$) and has negative weights associated with the faculty/student ratio ($\lambda_{\mathrm{FS}} = -0.4947$) and the university building space ($\lambda_{\mathrm{SP}} = -0.4862$). The faculty research and the full-professor ratio tend to be associated with the dimension of research and faculty quality, and the faculty/student ratio and university building space tend to signify the aspect of university quality that concerns the teaching and student learning environment. Therefore, the second principal component indicates a contrast between a university's research orientation and its teaching orientation. It is an index of the university's research/teaching intensity or mix. A university with a positive value of $P2$ is identified as more research-oriented; a negative value signals more emphasis on teaching. As the mean value of $P2$ is zero, an average university is neutral in research and teaching intensity. Statistically, the principal components are orthogonal and uncorrelated. A high-quality university could

3. Principal component method reduces the number of related measurements, such as (R, FS, PR, SP), needed to describe a common phenomenon, in this case the quality Q. Were the four variables perfectly correlated, any linear combination of the variables would serve as the quality index Q. In a less extreme case, principal component technique seeks to make the linear combinations of the variables (called principal components) to capture as much of the variations in (R, FS, PR, SP) as possible while at the same time being linearly independent of all other principal components. Mathematically, the first principal component is to find the coefficients (λ_R, λ_{FS}, λ_{PR}, λ_{SP}) that maximize the variation of the linear combination of the standardized variables in Equation (18). By the same token, the second principal component, uncorrelated to the first, seeks the second set of coefficients that maximizes the variation, and so on for the third and fourth principal components.

4. Established in 1959, the NSC supports, in the form of grants, research projects for educational and research institutions. The merit of the proposed project and the applicant's research records are the criteria for the support. However, the funding budget depends on the availability of the government's resource appropriation and is not based on the applicant's record. Thus, the number of granted projects per faculty, not the grand size, more appropriately serves as a proxy for the quality of faculty research.

TABLE 2
Definition of Variable and Sample Means

Variables	Comprehensive University	Science/Technology University	All Sample
Operating cost (billions NT$)			
C: total cost	2.433	1.019	2.094
Enrollments (thousands)			
U: undergraduate	9.372	8.748	9.222
G: graduate	2.354	0.881	2.000
Ph.D. program (dummy)			
Ph.D.: yes = 1; no = 0	0.875	0.458	0.775
Public university (dummy)			
Public: yes = 1; no = 0	0.485	0.479	0.485
Principal components:			
Q: first principal	0.227	−0.719	0.000
$P2$: second principal	0.071	−0.226	0.000
$P3$: third principal	−0.068	0.215	0.000
$P4$: fourth principal	−0.033	0.104	0.000
Quality-related variables			
R: NSC project per faculty	0.455	0.354	0.430
FS: faculty/student ratio	0.041	0.035	0.040
PR: full-professor ratio	0.256	0.118	0.223
SP: building space per student (square meters)	22.543	18.557	21.586

be either a research-oriented or a teaching-oriented university. The first two principal components account for 88.83% of the university quality variations in (R, FS, PR, SP). The other two minor components, $P3$ and $P4$, which together account for only 11.17%, are residual variations in quality and difficult to characterize.

Giving the sample means and sample standard deviations in Equation (18), the overall quality Q and the other three principal components $P2$, $P3$, and $P4$ for all-sample universities are computed as:

(19)

$$\begin{aligned}
Q_{it} &= -3.6342 + 1.8147 R_{it} + 34.1478\ \mathrm{FS}_{it} \\
&\quad + 2.9543\ \mathrm{PR}_{it} + 0.0389\ \mathrm{SP}_{it} \\
P2_{it} &= 0.7236 + 1.4194\ R_{it} - 33.7656\ \mathrm{FS}_{it} \\
&\quad + 3.6483\ \mathrm{PR}_{it} - 0.0374\ \mathrm{SP}_{it} \\
P3_{it} &= 0.4848 + 2.1243\ R_{it} - 34.5642\ \mathrm{FS}_{it} \\
&\quad - 2.9979\ \mathrm{PR}_{it} + 0.0296\ \mathrm{SP}_{it} \\
P4_{it} &= -0.5733 + 1.7455\ R_{it} + 34.0250\ \mathrm{FS}_{it} \\
&\quad - 0.2391\ \mathrm{PR}_{it} - 0.0461\ \mathrm{SP}_{it}
\end{aligned}$$

Table 2 tabulates the sample means of the variables. The average annual university operating expenses are around 2 billion NT dollars[5] in 2000–2003. The comprehensive universities incur much higher expenditure than the science/technology universities because of significantly larger enrollment, particularly in graduate programs. Slightly less than half of the sample universities are public institutions. The comprehensive universities have higher research activity (R), higher FS, more full professors (PR), and more facility space (SP), than the science/technology universities. By construction, the principal components have zero mean. According to the values of the first principal component (Q), Table 2 shows that, in general, a typical comprehensive university has higher quality than a typical science/technology university. As judged by the second principal component ($P2$), the comprehensive university is more research-intensive or oriented, whereas the science/technology university is more oriented toward teaching.

In the empirical model (Equation (17)), the overall quality shifts the marginal cost of undergraduate and graduate production by the smooth

5. The average exchange rate during the periods 2000–2003 of 1 US dollar is to 34.20 New Taiwan (NT) dollars.

coefficient functions, $\beta_U(Q_{it})$ and $\beta_G(Q_{it})$:

$$\text{(20)}\quad \begin{aligned} MC_U &= \beta_U(Q_{it}) + \beta_{UU}U_{\text{it}} + \beta_{UG}G_{it} \\ MC_G &= \beta_G(Q_{it}) + \beta_{UG}U_{\text{it}} + \beta_{GG}G_{it} \end{aligned}$$

It is expected that these smooth coefficient functions, $\beta_U(Q)$ and $\beta_G(Q)$, are increasing function of the quality (Q). Higher quality increases the marginal costs of outputs. Furthermore, the offering of a Ph.D. program is likely to increase the total cost, $\beta_{\text{PhD}}(Q_{it}) > 0$, and its marginal increment depends on the overall quality of the institution:

$$\text{(21)}\quad MC_{\text{PhD}} = \beta'_{\text{PhD}}(Q_{it})$$

The cost-quality relation is profiled in the marginal cost of the overall quality:

$$\text{(22)}\quad \begin{aligned} MC_Q = {} & \beta'_0(Q_{it}) + \beta'_U(Q_{it})U_{it} + \beta'_G(Q_{it})G_{it} \\ & + \beta'_{\text{PhD}}(Q_{it})\text{PhD}_{it} \end{aligned}$$

The semiparametric specification of the cost function (Equation (17)) with the first principal component as the overall quality index Q in fact nests the following two statistically identical parametric specifications as special cases:

$$\text{(23)}\quad \begin{aligned} C_{it} = {} & \beta_0 + \beta_U U_{it} + \beta_G G_{it} + \beta_{\text{PhD}}\ \text{PhD}_{it} \\ & + (1/2)\beta_{UU}U_{it}^2 + \beta_{UG}U_{it}G_{it} \\ & + (1/2)\beta_{GG}G_{it}^2 + \alpha_{\text{public}}\ \text{Public}_{it} + \beta_Q Q_{it} \\ & + \beta_{P2}P2_{it} + \beta_{P3}P3_{it} + \beta_{P4}P4_{it} + \varepsilon_{it} \end{aligned}$$

and

$$\text{(24)}\quad \begin{aligned} C_{it} = {} & \alpha_0 + \beta_U U_{it} + \beta_G G_{it} + \beta_{\text{PhD}}\ \text{PhD}_{it} \\ & + (1/2)\beta_{UU}U_{it}^2 + \beta_{UG}U_{it}G_{it} \\ & + (1/2)\beta_{GG}G_{it}^2 + \alpha_{\text{public}}\ \text{Public}_{it} + \alpha_R R \\ & + \alpha_{\text{FS}}\ \text{FS}_{it} + \alpha_{\text{FR}}\ \text{PR}_{it} + \alpha_{\text{SP}}\ \text{SP}_{it} + \varepsilon_{it} \end{aligned}$$

The nesting of Equation (23) is obvious when $\beta_Q(Q_{it}) = \beta_0 + \beta_Q Q_{it}$, and other coefficients, $\beta_U(Q_{it})$, $\beta_G(Q_{it})$, and $\beta_{\text{PhD}}(Q_{it})$, are constant. The nesting of Equation (24), however, is because of the fact that the four principal components, (Q, $P2$, $P3$, $P4$), together account for the total variation of the four quality-related indexes, (R, FS, PR, SP). The hypothesis that the parametric cost function (Equation (23) or (24)) is a correct specification against the alternative semiparametric cost function (Equation (17)) can then be stated as:

$$H_0: \begin{pmatrix} \beta_0(Q) \\ \beta_U(Q) \\ \beta_G(Q) \\ \beta_{\text{PhD}}(Q) \end{pmatrix} = \begin{pmatrix} \beta_0 + \beta_1 Q \\ \beta_U \\ \beta_G \\ \beta_{\text{PhD}} \end{pmatrix}$$

The J_n statistic of Equation (14) is used to test this hypothesis.

IV. EMPIRICAL RESULTS

Two university cost regressions are estimated, the semiparametric smooth coefficient regression Equation (17) and the parametric regression Equation (23).[6] The results are provided in Table 3. As the semiparametric estimates of $\beta_0(Q)$, $\beta_U(Q)$, $\beta_G(Q)$, and $\beta_{\text{PhD}}(Q)$ are functions of the overall quality Q, the values given in Table 3 are the means over the 200 estimated points and the respective ranges.[7] In general, the overall models, both parametric and semiparametric, fit reasonably well and are quite similar. Most coefficient estimates are statistically significant at the 5% level, except β_{UU}, β_{P4} in the parametric model, and β_{UG}, β_{P2} in the semiparametric model. Other things being equal, a public institution costs less, and a more research-intensive university costs more based on the parametric estimate. However, the semiparametric estimate of β_{P2} is negative but insignificant. On average, both β_Q and $\beta_0(Q)$ are positive and statistically significant. Thus, quality education does cost more. By examining the result more closely, however, the parametric results are quite misleading. The null hypothesis that the parametric model is a correct specification is rejected at the 1% significant level with the test statistic $J_n = 15.58$. The overall quality is a nonneutral, cost-shifting factor in the university operating cost. Figures 1A and 1B plot the estimates $\beta_0(Q)$, $\beta_U(Q)$, $\beta_G(Q)$, $\beta_{\text{PhD}}(Q)$, and their 90% lower and upper bounds. As the intercept is not identifiable in the semiparametric regression, the smooth coefficient function $\beta_0(Q)$ in Figure 1A is compared with the parametric estimate ($\beta_0 + \beta_Q Q$). Most of the straight

6. As the regression Equation (24) is statistically identical to Equation (23), the estimates of β_U, β_G, β_{PhD}, β_{UU}, β_{UG}, β_{GG}, β_{Public} in Equation (24) are the same as in Equation (23). Other estimates of regression in Equation (24) are $\alpha_0 = -1.225741$, $\alpha_R = 0.813857$, $\alpha_{\text{FS}} = 14.94186$, $\alpha_{\text{PR}} = 2.417267$, and $\alpha_{\text{SP}} = 0.007542$.

7. These ad hoc mean estimates are tabulated simply for the purpose of comparison with the parametric estimates.

TABLE 3
Parametric and Semiparametric Estimation

	Parametric Model		Semiparametric Model	
	Coefficient	**t-Value**	**Coefficient**	**Range/t-Value**
β_0	0.418381	1.762142		
β_Q	0.467132	7.107532		
$\beta_0(Q)$			0.162960	(0.0964, 0.5310)
β_U, $\beta_U(Q)$	0.155126	4.649518	0.049051	(0.0463, 0.0675)
β_G, $\beta_G(Q)$	−0.211837	−2.186696	0.269455	(0.0973, 0.3816)
β_{PhD}, $\beta_{\text{PhD}}(Q)$	0.428895	3.062074	0.606397	(−0.0445, 0.6792)
β_{UU}	0.000032	0.012037	0.007006	5.763794
β_{UG}	0.011824	1.666702	0.004165	0.648576
β_{GG}	0.097356	4.251328	0.045658	2.503267
β_{Public}	−0.601929	−4.046463	−0.182513	−2.320726
β_{P2}	0.173416	2.010392	−0.035158	−0.494791
β_{P3}	−0.135689	−1.716004	−0.124289	−1.479108
β_{P4}	0.003493	0.030370	0.258521	2.265578
Test statistics: J_n	15.584483			

Notes: The coefficient estimates in the semiparametric model are the sample average over 200 observations. The numbers in brackets are the sample ranges of the estimates. These ad hoc mean estimates are simply for the purpose of comparison with the parametric estimates.

line of the parametric estimate is outside the 90% bound except within a very small range of the overall quality Q value.[8] As illustrated in Equation (20), the varying coefficients $\beta_U(Q)$ and $\beta_G(Q)$ measure the impact of Q on U and G in shifting the marginal cost. The increasing trends shown in Figures 1B and 1C indicate that, other things being equal, the cost of an additional enrollment is higher as the quality increases, especially in the case of graduate expansion. The positive trends in $\beta_U(Q)$ and $\beta_G(Q)$ have significant implications on the economies of scale. The estimates, $\beta_U = 0.1551$ and $\beta_G = -0.2118$ from the parametric model are clearly outside the 90% bounds. Figure 1D indicates that the cost of having a Ph.D. program is much higher for the lower-quality institutes than for the high-quality institutions. It is much harder and more costly for a lower-quality institution to start up and to operate a viable Ph.D. program than for a well-established and reputable institution. Table 4 shows the estimates of the marginal cost of overall quality, undergraduate, and graduate education. The marginal cost of the graduate program is more than threefold of the undergraduate in all categories of institutions. In general, the overall quality in public and comprehensive universities is higher than in private and science/technology universities in Taiwan; the marginal cost or the shadow price of the overall quality is positive. Quality education does cost more, particularly, in public and comprehensive universities.

8. When the parametric regression with the squared Q variable is included (not shown in the figure), the estimate $\beta_0 + \beta_Q Q + \beta_{QQ} Q^2$ has a similar linear trend as in Figure 1A.

The estimates of the ray and product-specific economies of scale are tabulated in Table 5. Ray and product-specific economies of scale occur when the estimate is greater than one. The parametric cost regression tends to overestimate both the ray and the product-specific scale economies. The parametric cost regression shows ray economies of scale, except in science/technology universities. However, in the case of the semiparametric cost regression where the nonneutral quality impact is accounted for, it shows ray diseconomies or near constant returns to scale for all categories of universities. The parametric results show near constant returns to scale for the undergraduate program while the semiparametric results indicate otherwise. The undergraduate program at all categories shows diseconomies of scale. The scale of the undergraduate program is well beyond the minimum cost optimal scale. However, both parametric and semiparametric estimation show economies of scale for the graduate program, except in the science/technology university based on the parametric estimation.

How much does quality affect the scale economies? The measure of the ray economies of scale RES illustrated in Equation (4) is a

FIGURE 1
Semiparametric Estimates and 90% Lower/Upper Bound

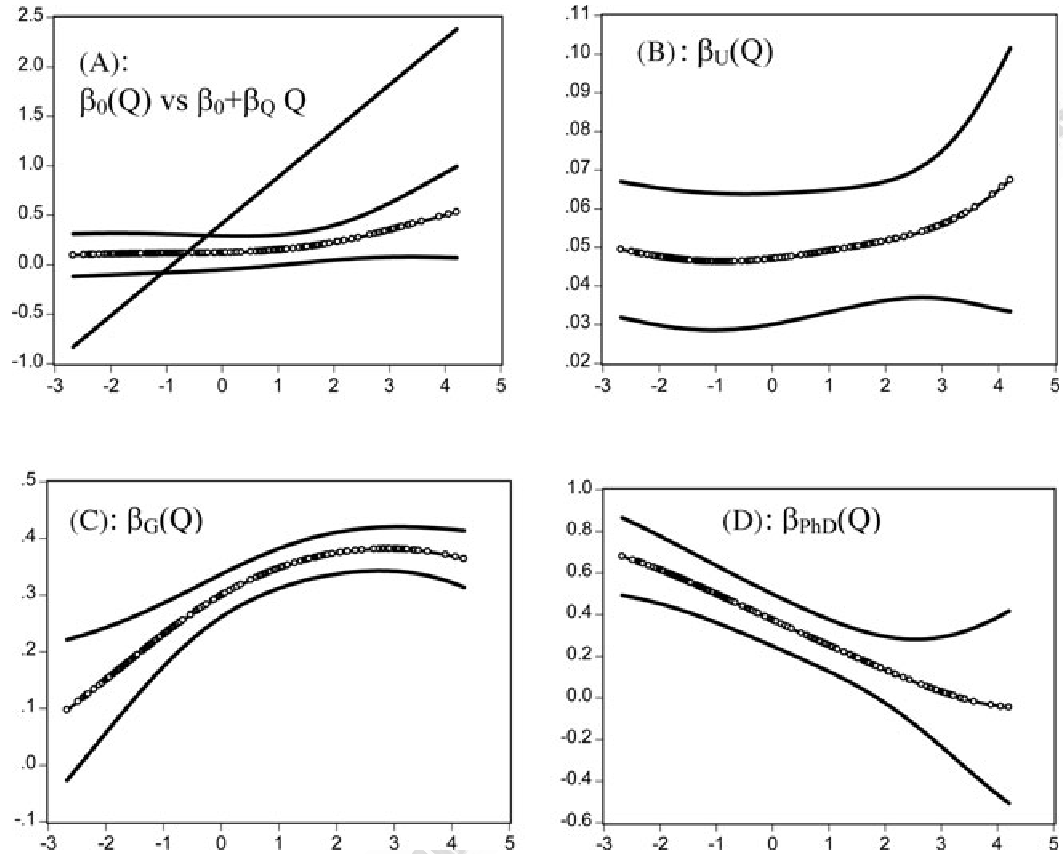


TABLE 4
Semiparametric Estimates of the Marginal Cost of Quality, Undergraduate, and Graduate Outputs

	MC_Q	MC_U	MC_G
All samples	0.0477	0.1213	0.4159
Comprehensive university	0.0563	0.1251	0.4341
Science/technology university	0.0205	0.1094	0.3583
Public university	0.0798	0.1094	0.4385
Private university	0.0176	0.1326	0.3946

function of overall quality. To be more precise, we denote the measure as RES(Q_{it}) to emphasize the dependency. The ray economies values in Table 5 are the mean value of RES(Q_{it}) evaluated at the individual university's quality at time t. As higher quality incurs higher educational cost, the positive trends in $\beta_U(Q_{it})$ and $\beta_G(Q_{it})$ will have implications for the economies of scale. Figure 2 simulates the variation of scale economies at various quality levels. For example, if the quality of each and every university were at the median value (50 percentile) of Q, the sample mean of the ray economies of scale would be RES(Q_{50}) = 1.0492, and at the 80th percentile, RES(Q_{80}) = 0.9421. In this scenario, Figure 2 shows that in all categories of the university, except for science/technology, higher education would be subject to economies of scale at the median quality.[9] As the quality level increases beyond the 70th percentile, every category would be subject to diseconomies of scale. The implication from this simulation is that the current university scale in Taiwan is too big, particularly

9. The sample mean quality Q for all-sample corresponds to the 57th percentile (Q_{57}).

TABLE 5
Ray Scale Economies and Product-Specific Scale Economies

	RES	PSE_U	PSE_G
All samples			
Parametric	1.3739	0.9992	1.6742
Semiparametric	0.9955	0.7533	1.3946
Comprehensive university			
Parametric	1.5017	0.9992	1.9022
Semiparametric	1.0248	0.7575	1.4259
Science/technology university			
Parametric	0.9694	0.9992	0.9524
Semiparametric	0.9024	0.7399	1.2957
Public university			
Parametric	1.5800	0.9995	1.2152
Semiparametric	0.9953	0.8017	1.3464
Private university			
Parametric	1.1799	0.9989	2.1065
Semiparametric	0.9955	0.7077	1.4401

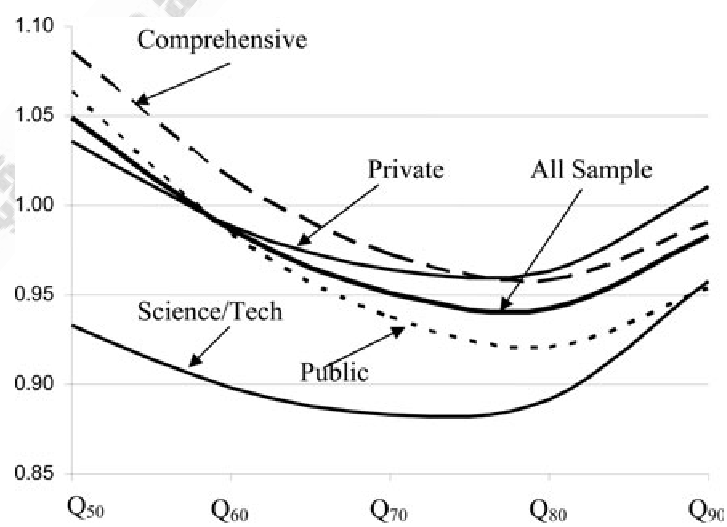
in the science/technology university, to be cost efficient.

V. CONCLUSIONS

Quality education is costly. The quality raises the average cost of university operation and also its impact on the university cost of operation depends on the university's mission and orientation in undergraduate and graduate education. Quality is not simply a neutral, cost-shifting factor. In this paper, a semiparametric smooth coefficient cost model is proposed to study the university cost structure. The smooth coefficients are a function of a university's overall quality in research, in faculty, in faculty/student ratio, and in the educational environment measured in facility space. Because the smooth coefficients of the cost function are unspecified, the semiparametric model provides an alternative to the conventional parametric model. Using panel data from 56 comprehensive and science/technology universities in Taiwan, the paper estimates the economies of scale and the shadow price of quality. The empirical results confirm that quality is indeed a nonneutral cost-shifting factor and the marginal cost of graduate education is more than three times that of undergraduate education. Taking quality into account, we can see that higher education in Taiwan is subject to diseconomies of scale. In all categories—comprehensive and science/technology and public and private universities—the current university scale in Taiwan is too big to be cost efficient.

The focus in this paper is on the cost aspect of university structure in Taiwan. Obviously, the cost of delivering higher education is only one important factor to a college or university operation. The number of colleges and universities in Taiwan has increased rapidly in

FIGURE 2
Ray Economies of Scale at Various Quality Percentile



the last two decades. As of 2003, there were 139 colleges and universities compared to only 26 institutions in 1980, and during the same period, the number of students increased five-fold. This extraordinary expansion coupled with the declining birth rate has resulted in the availability, if not the affordability, of college education to virtually anyone with the matriculation rate of 100% in 2008. Many financially strapped colleges and universities are facing the danger of closing as a result of lack of students and declining tuition revenue. It is a real challenge a university faces on the issues of balancing the cost, revenue, or even the bottom line (profit or loss) and delivering quality higher education. Hoenack and Weiler (1975, 1979) and Berg and Hoenack (1987) have long advocated the policy of cost-related tuition by differentiating tuition by program level (such as undergraduate and graduate programs, liberal arts division and professional school, or even by courses) to increase efficiency in higher education and in the labor markets it serves. Cost-related tuition policy will certainly change the size and composition of university enrollments because it will alter the students' enrollment decision. The implementation of the cost-related tuition policy in Taiwan requires further research on demand for higher education and the market demand for graduates, which is beyond the scope of university cost structure and scale economies addressed in this paper.

APPENDIX

In Section III, we define an overall university quality index. Based on the data from 56 universities in Taiwan, the following table shows the correlation coefficients between the average cost (AC) and the three variables: the quality index (Q), the undergraduate (U) enrollment, and the graduate (G) enrollment. In general, the correlation coefficients for the above medium quality universities are much higher than for the bottom half; the graduate program seems to be associated with a higher average cost than the undergraduate program. This result provides a preliminary evidence of the program-specific marginal cost-quality relation and reassures us about the justification of formulating the nonneutral cost-shifting function (Equation (1)). The simple scatter plot of the average cost against the quality index shows a highly nonlinear relationship globally over the entire sample range. Thus, empirically a sensible way to estimate to the cost structure is the local least square method.

Correlation between AC and Q, U, G

University	Q	U	G
Above medium	0.81	0.13	0.35
Below medium	0.46	0.08	0.28

The basic idea of the local least squares of Li et al. (2002) is the weighted least squares technique. Consider an illustrative linear regression with the smooth coefficients as unknown functions of Q, that is, $Y_t = \alpha(Q) + \beta(Q)X_t + \varepsilon_t$. Suppose one estimates the varying coefficients, $\alpha(Q_o)$ and $\beta(Q_o)$ at point Q_o, using only observations that lie in a neighborhood of Q_o, which is denoted as $N(Q_o)$. If the included observations within the neighborhood were given equal weights, the "local" (neighborhood) least squares estimation would solve the minimization, $\min_{\alpha,\beta} \sum_{Q_t \in N(Q_o)} (Y_t - \alpha(Q_o) - \beta(Q_o)X_t)^2$, where the dependence of the coefficients on Q_o is emphasized. In repeating the above procedure to a series of points Q, one obtains the local least squares estimation of the smooth coefficient regression. Alternatively, one could use an unequal weighting scheme that assigns higher weights to observations closer to Q_o and lower weights to observations further away. For example, a weighting function, commonly known as kernels, may be a normal density function centered at Q_o that declines in either direction. The local least squares estimation becomes $\min_{\alpha,\beta} \sum_t (Y_t - \alpha(Q_o) - \beta(Q_o)X_t)^2 K\big((Q_t - Q_o)/h\big)$, where the kernel function $K(.)$ is the standard Gaussian kernel, and the parameter h, known as the bandwidth, determines the magnitude of the density and hence the size of the neighborhood. Other kernel functions such as the uniform kernel which takes the value of ½ on $(-1, 1)$ and 0 elsewhere are also often used in practice. The uniform kernel applies equal weight within the interval $Q_o \pm h$. Thus, the local least squares estimation is simply the minimization of the observations that lie in the interval, that is, $\min_{\alpha,\beta} \sum_{|Q_t - Q_o| \le h} (Y_t - \alpha(Q_o) - \beta(Q_o)X_t)^2$. Generally, the selection of kernel is less important than the selection of bandwidth (i.e., the neighborhood of Q_o) over which observations are weighted. As the coefficients $\beta(Q)$ are a smooth function of Q, intuitively the absolute difference $|\beta(Q_t) - \beta(Q_o)|$ is small when $|Q_t - Q_o|$ is small. Therefore, if $n \times h$ is large, it would ensure that there are a sufficient number of observations within the interval $|Q_t - Q_o| \le h$ when $\beta(Q_t)$ is close to $\beta(Q_o)$. Hence, under the conditions such as the bandwidth $h \to 0$ and $nh \to \infty$, the local least squares estimator $\hat{\beta}(Q_o)$ from the above minimization provides a consistent estimator of $\beta(Q_o)$. A similar argument can be applied to the consistent estimator $\hat{\alpha}(Q_o)$.

The bandwidth h is set to be the mean-square-error-minimizing bandwidth, that is, the minimization of residual variance $\hat{\sigma}_\varepsilon^2(h) = (1/n)\sum_{i=1}^n (C_t - X_t^T \overline{B}(Q;h))^2$, where the dependence of the variance $\hat{\sigma}_\varepsilon^2(h)$ and the coefficient $\overline{B}(Q;h)$ on the bandwidth h is emphasized. For the standard Gaussian kernels, the optimal bandwidth is $h = 1.06 Q_{\mathrm{sd}} n^{-1/5}$, where Q_{sd} is the sample standard deviation of Q. Although one may use the mean-integrated-square-error minimizing kernel of the Epanechnikov or some data-driven method such as the cross-validation method to select h, we did not consider them in our empirical investigation. Given the quality observations Q_t, which is to be defined later, the standard Gaussian kernels in Equation (9) at Q is equal to

(A1)
$$K\big((Q_t - Q)/h\big) = (1/\sqrt{2\pi}) \exp\big(-1/2\big((Q_t - Q)/h\big)^2\big)$$

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